

# Cosmic acceleration from effective forces?

Dominik J. Schwarz<sup>1</sup>, Winfried Zimdahl<sup>2</sup>, Alexander B. Balakin<sup>3</sup>, and Diego Pavón<sup>4</sup>

<sup>1</sup> Institut für Theoretische Physik, Technische Universität Wien,  
Wiedner Hauptstraße 8-10, A-1040 Wien, Austria

<sup>2</sup> Fachbereich Physik, Universität Konstanz,  
Postfach M678, D-78457 Konstanz, Germany

<sup>3</sup> Department of General Relativity and Gravitation, Kazan State University,  
RU-420008 Kazan, Russia

<sup>4</sup> Departamento de Física, Universidad Autónoma de Barcelona,  
E-08193 Bellaterra (Barcelona), Spain

**Abstract.** Accelerated expansion of the Universe may result from an anti-frictional force that is self-consistently exerted on cold dark matter (CDM). Cosmic anti-friction is shown to give rise to an effective negative pressure of the cosmic medium. While other models introduce a component of dark energy besides “standard” CDM, we resort to a phenomenological one-component model of CDM with internal self-interactions. We demonstrate how the dynamics of the  $\Lambda$ CDM model may be recovered as a special case of cosmic anti-friction [1].

Measurements of supernovae of type Ia at high redshifts provide evidence that the expansion of the Universe accelerates [2,3,4] and there are first observational indications that this acceleration sets in at a redshift below  $z \sim 1$  [5]. Observational aspects and some cosmological consequences of high- $z$  supernovae have been discussed by R. Kirshner at this conference [6]. In our contribution we point out that other explanations besides introducing a cosmological constant or another scalar (“quintessence”) field are possible.

Recently, the spatial geometry of the Universe has been measured by means of the temperature fluctuations in the cosmic microwave background (CMB) [7,8]. Based on a seven parameter fit the Boomerang team finds for the spatial curvature  $\Omega_k = 0.03 \pm 0.06$  (value for weak priors) [7], which is consistent with a spatially flat Universe.

The combination of CMB and high- $z$  supernova data shows that dust (vanishing pressure  $P$ ) alone cannot make up all of the mass in the Universe. An obvious solution to this problem is provided by a cosmological constant, parameterised by  $\Omega_\Lambda$ . However, this solution is plagued by heavy theoretical problems: Why is  $\Omega_\Lambda$  so small? Why can we see it just know? While the first question is probably one of fundamental physics, an answer to the second question may come from cosmology. To avoid this “coincidence problem”, models with a new scalar field (“quintessence” [9]) have been introduced. These models can be characterised by the density of the scalar field,  $\Omega_\phi$ , and its equation of state  $w_\phi \equiv P_\phi / \rho_\phi$ .

In the following we present an alternative explanation of CMB and high- $z$  supernova data in which one does not introduce another dark component besides

CDM (see [1] for more details). Instead we add an extra force that acts on CDM. For non-relativistic CDM particles the most general force which is compatible with the cosmological principle was shown to reduce to

$$\mathbf{F} = -B(z)m\mathbf{v}, \quad (1)$$

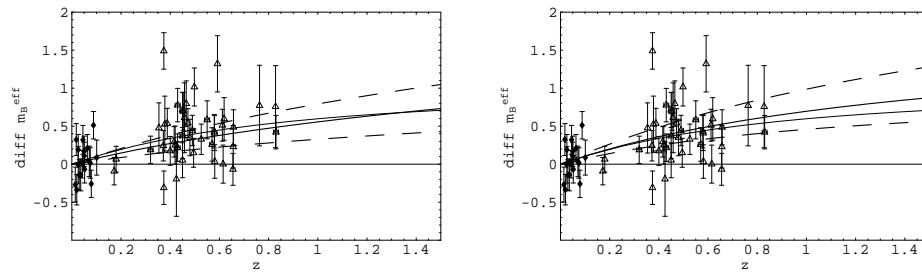
where  $m$  is the mass of the particles and  $\mathbf{v}$  their peculiar velocity. This force is directed parallel or anti-parallel to the motion of the individual CDM particles. The quantity  $B(z)$ , which has the dimension of an inverse time, obviously plays the role of a coefficient of (anti-)friction. Macroscopically, the action of a force of this type generates an effective viscous pressure. Thus it is not allowed to describe CDM by a perfect fluid in that case. The exact expression for the dynamic pressure in the presence of (anti-)frictional forces reads

$$P = \frac{B}{H}\rho, \quad (2)$$

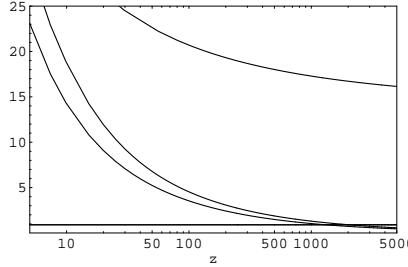
which gives rise to an accelerated expansion of the Universe if  $B < -H/3$ , thus in the case of anti-friction. In our calculation we have assumed that the CDM particle distribution is invariant with respect to elastic collisions (the collision term in the kinetic equation vanishes), which implies that a negative pressure is related to the phenomenon of particle production.

Even without having a microscopic model for cosmic anti-friction at hand we can check this idea by a comparison with the data. We need to make an ansatz for  $B(z)$ . It is natural to assume  $B = -\mathcal{O}(H_0)$ , since  $H_0$  is the only rate that is distinguished by cosmology. In [1] we investigated three different models, which all fit the supernova data. Figure 1 shows the prediction for two different models. With the help of the CMB data we can rule out one of our models. The two other models seem to be consistent, as is shown in figure 2.

It turns out that our third ansatz  $B = -\nu H_0^2/H$ , where  $\nu$  is a constant, is dynamically equivalent to the  $\Lambda$ CDM model, since  $P = -\nu\rho_0$  in that case. This ansatz fits both the CMB and the supernova data and predicts an onset



**Fig. 1.** Differences of the magnitudes with respect to a  $(\Omega_M, \Omega_\Lambda) = (1, 0)$  universe versus redshift. The data points are taken from [3]. The thin line denotes the  $(\Omega_M, \Omega_\Lambda) = (0.3, 0.7)$  universe. For the lhs figure we assume  $B = -\nu H$  and plot the predictions for  $\nu = 0.7, 0.5, 0.3$  (thick lines from top to bottom). For the figure on the rhs we assume  $B = -\nu H_0$  with  $\nu = 0.9, 0.7, 0.5$  (thick lines from top to bottom).



**Fig. 2.** The angular scale under which the Hubble horizon at redshift  $z$  would be observed today. The horizontal line is the angular scale,  $0.9^\circ$ , of the first acoustic peak in the CMB temperature spectrum. The curves show our three models  $-B \propto H$ ,  $H_0$ ,  $1/H$  (from top to bottom), respectively. The first model is excluded by the CMB data, the last one is dynamically equivalent to  $\Lambda$ CDM.

of acceleration at  $z_{\text{acc}} \approx 0.7$ , but with the important difference that there is no separate dark energy component. This degeneration with  $\Lambda$ CDM may be resolved by investigating large scale structure or clusters. Naively, one might think that cluster data [10] immediately rule out  $\Omega_M = 1$ . However, one should keep in mind that  $\Omega_{\text{cluster}}$  typically is obtained under the assumption that CDM is a perfect fluid. In general relativity the gravitating mass is given by  $\rho + 3P$ , thus if there were a similar negative dynamic pressure at cluster scales, the matter densities from clusters could be underestimated.

We have shown that effective anti-frictional forces could explain the accelerated expansion of the Universe. An interesting hint for finding a microscopic model of cosmic anti-friction might be that it is the cosmological scale  $1/H_0$  that gives rise to the correct order of magnitude, which seems to suggest a gravitational mechanism.

D.J.S. thanks the Austrian Academy of Sciences for financial support. This work was also supported by the Deutsche Forschungsgemeinschaft and NATO.

## References

1. W. Zimdahl, D. J. Schwarz, A. B. Balakin and D. Pavón, Phys. Rev. D **64**, 063501 (2001)
2. A. G. Riess et al., Astron. J. **116**, 1009 (1998)
3. S. Perlmutter et al., Astrophys. J. **517**, 565 (1999)
4. A. G. Riess, PASP **112**, 1284 (2000)
5. A. G. Riess et al., [astro-ph/0104455](#)
6. R. Kirshner, this volume
7. C. B. Netterfield et al., [astro-ph/0104460](#)
8. A. T. Lee et al., [astro-ph/0104459](#); N. W. Halverson et al., [astro-ph/0104489](#)
9. R. R. Caldwell, R. Dave and P. J. Steinhardt, Phys. Rev. Lett. **82**, 896 (1998)
10. R. Carlberg et al., Astrophys. J. **478**, 462 (1997); N. Bahcall et al., Astrophys. J. **541**, 1 (2000)